

## PROFILE DATA COMPARISONS FOR AIRFIELD RUNWAY PAVEMENTS

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## ABSTRACT

The Federal Aviation Administration (FAA)'s Advisory Circular (AC) 150/5380-9 does not recommend use of inertial profilers that include highpass filtering for measuring profiles which are to be used for computing Boeing Bump Index (BBI) or simulated aircraft accelerations on airport pavements [1]. This paper introduces the influences of the highpass filtering on BBI and aircraft accelerations. Therefore, rationales to exclude the highpass filtering which is adopted for highway pavement profiling are provided. The FAA William J. Hughes Technical Center (WJHTC) owns inertial profiling system, SurPro walking profiler, Dipstick, and highway profiling system were used for data collections. Longitudinal profile data was collected from test pavement sections including the Smart Road test facility located at Blacksburg, Virginia. The FAA roughness program, ProFAA, was used for processing the collected profiles. Since there are unknown procedures for signal processing in highway profiling systems, airport profiles from the FAA inertial profiler were filtered with multiple level of wavelengths ranging from 100 feet to 500 feet. After the highpass-filtered profiles were generated by ProFAA, comparisons were made with original profiles from the FAA profiler and from the highway profiler. The profiles from the walking profiler and dipstick are also included for the comparisons. Arbitrary bumps with different wavelength and height were created for wavelength sensitivities using the aircraft simulation function in ProFAA. The sensitivity analysis presented effective wavelengths required for airport runway pavements for given conditions in terms of accelerations at the aircraft cockpit and center of gravity.

## INTRODUCTION

In addition to increasing interests for wavelengths such as ASTM activities for revision of ASTM E950-98 (2004), recently developed new standard for 25 feet CA Profilograph simulation in ASTM E2955-13, and a task group for BBI computations, there are significantly different perspectives between airfield roughness and highway roughness as described in the FAA AC 150/5380-9 [1, 2, 3]. The AC introduces usage of the Boeing Bump for airfield roughness which is defined in terms of fatigue on aircraft components (increase stress and wear) and/ or other factors which may impair the safe operation of the aircraft (cockpit vibrations, excessive g-forces, etc.). Undesirable elevation changes on runway pavements can increase stress on aircraft components, reduce braking action, make it difficult for pilots to read cockpit instrumentation, and/or cause discomfort to passengers. Typically, long wavelength bumps are the most prevalent but are not usually visible to the naked eye. Highway roughness does not consider the longer wavelength which is needed to quantify airfield roughness because the passenger vehicles and trucks stressing on highway pavements have shorter axle spacing comparing to much longer wheelbase of aircrafts on airfield pavements. For example, B727-200 has 63.25 feet wheelbase. Longitudinal profile data was collected from test pavement sections including the Smart Road test facility located at Blacksburg, Virginia. An inertial airfield profiler without highpass filter collected pavement surface profile data, processed, and compared with highway profiler including highpass filter collected data. The comparisons showed the frequencies of highpass filtering in highway profiler, and the recognized methods need to be inactivated to use the profiler for airfield pavements. The comparisons were made by computed BBI and aircraft simulations, and by different types of profiling devices. Influences of the highpass filtering on BBI and aircraft accelerations are introduced and discussed. The FAA roughness program, ProFAA, was used for the data processing, index computations, and aircraft accelerations.

Additional analysis on arbitrary bumps with different wavelength and height were conducted to see the sensitivity of aircraft responses on the bumps.

## **PROFILING DEVICE**

The FAA developed a customized inertial profiler (FIP) is composed of vertical displacement measuring device, Distance Measuring Instruments (DMI), and an accelerometer. The device shown in Figure 1 meets or exceeds the requirements of ASTM standard E950-98 (2004) [2]. The LMI manufactured Selcom laser as a vertical displacement device collects vertical elevation change data at 64 kHz sampling rate with 0.04 inches spot size. Distance traveled by the test vehicle along the pavement is measured with a speed sensor, or a direct-reading distance traveled sensor. The essential element of an inertial profiling device, which makes the technique feasible, is a high-quality accelerometer. In essence, the accelerometer is the hardware for a single-axis inertial navigation system and is used to measure the absolute vertical position of a point on the test vehicle (the vertical position relative to an inertial reference). The accelerometer is mounted on the test vehicle with its sensitive axis aligned in the vertical direction. Vertical position is computed by double integrating the accelerometer output signal. The distance from the accelerometer mounting point to the surface of the pavement is measured with the Selcom laser. The combination of the two measurements then gives the absolute elevation of the pavement surface. The three sensors used in the FAA's profiling device are:

- Vertical Displacement: Selcom 2207 Optocator Laser Sensor
- DMI: Datron DLS-2 Optical Speed and Distance Sensor
- Vehicle Elevation: Allied Signal QA700 Accelerometer

Knowing that the inclinometer type profiler is based on purely as measured angles for a given unit distance, the FAA WJHTC owned Dipstick and SurPro devices were used for longitudinal profiling as well. The FAA owns Dipstick 2272 and SurPro 2000 inclinometer profilers collected longitudinal profile data at the same time the inertial profiling devices, and the collected data were compared with the FAA inertial profiler data without highpass filtering. The comparison was performed to validate that the FAA inertial profiler data was not transformed by highpass filtering.



Figure 1. FAA Inertial Profiler (FIP) Mounted on A Passenger Vehicle.

The FAA purchased Dynatest/KJL6850 runway friction tester equipped with a Dynatest 6650 inertial profiler for runway profile data collection used as a highway inertial profiler. As typical inertial profiling devices, the profiler is an automated profile measurement device consisting of optical displacement measurement sensor, distance measurement system, and accelerometer. The optical displacement sensor is a laser mounted in level for proper operation at 10 inches above the ground. The distance measurement system has a wheel mounted digital encoder. Encoder pulses are counted to determine the distance traveled. The accelerometer is located on top of the laser displacement case.

## TEST CONDITION

The FAA owned inertial profiler representing airfield roughness profiler without highpass filtering and the Dynatest vehicle representing highway profiler were used to collect longitudinal pavement surface profiles at pavement test sections located at the FAA WJHTC, New Jersey, and Smart Road test facility at Blacksburg, Virginia. For comparison purposes with inertial profiling devices, the FAA owned walking profilers, SurPro and Dipstick, were also used for profile data collections.

### Preliminary Test Section at FAA WJHTC

As a preliminary test, a 3,000 feet long tangent section in asphalt concrete pavement at Reservoir Road located at the FAA WJHTC was selected for profiler calibrations and comparisons. The calibrations were made for Datron for distance and LMI Selcom for vertical elevations. Longitudinal profiles on the asphalt pavement surface were measured following the yellow dotted line with start and end points marked by red lines on Figure 2.



Figure 2. A 3,000 feet Profiler Test Section at Atlantic City International Airport (courtesy of maps.google.com).

The pavement surface profiles at the test section were measured using FIP, Dynatest, and SurPro. The measurement speeds were varied with profiler types. For high speed profilers such as FIP and the Dynatest profiler, the driving speed was maintained at 30 mph with 1 inch data collection rating. The SurPro was operated at normal measurement speed, at average 0.8 mph (=1.2 fps) with 12 inches data collection rating. Figure 3 depicts measurement directions with the sensor location for vertical elevations changes for each profiler.

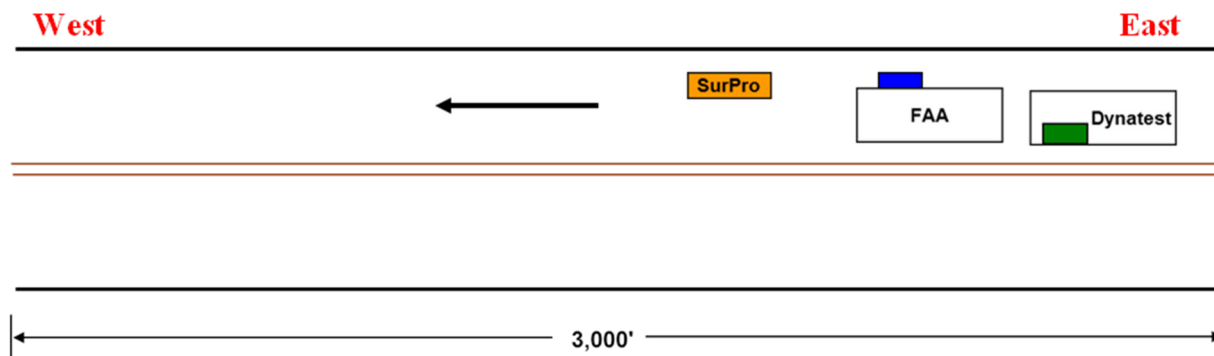


Figure 3. Sensor Location for Each Profiler At 3,000 feet Profiler Test Section in Atlantic City International Airport. 30 mph Driving Speed (FAA & Dynatest).



### Virginia Smart Road

As described on <http://www.vtti.vt.edu/smart-road/virginia-smart-road.html>, the Virginia Smart Road, which was selected for the profiler comparison study, is a closed test-bed research facility managed by Virginia Tech Transportation Institute (VTTI) and owned and maintained by the Virginia Department of Transportation (VDOT). The research facility is located in Blacksburg, Virginia and was built as a 2.2 mile-long test pavement including asphalt and concrete pavements. Approximately 1.85 mile-long pavement sections are selected excluding loop areas for profile data collection at tangent line. The selected pavement sections in the facility are shown in Figure 4.

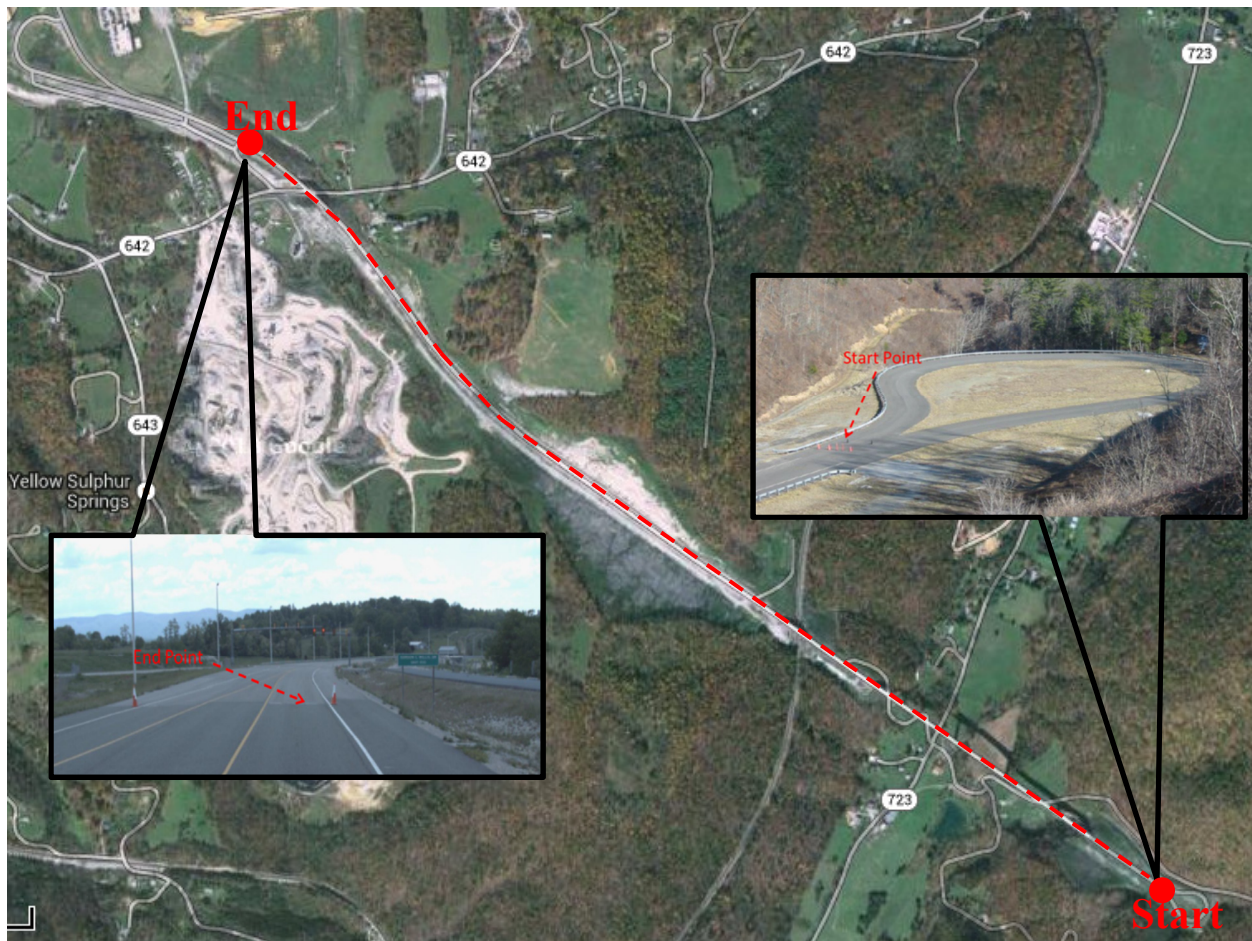


Figure 4. Selected Pavement Sections for Profile Data Collection at Smart Road in Blacksburg, Virginia (courtesy of maps.google.com).

The pavement surface profiles at the test sections were measured using high speed inertial profilers, FIP and the Dynatest profilers, representing airfield without highpass filter and highway profiler with highpass filter, respectively. The walking profilers: SurPro and Dipstick were also used for collecting profile data. As conducted in the preliminary testing at the FAA WJHTC, the FIP and Dynatest profiler were operated at 30 mph with 1 inch data collection

rating. SurPro and Dipstick were operated at normal measurement speed at average 1.2 fps with 12 inch data collection rating.

## RESULT

Longitudinal profile data collected from four different profiling devices with different mechanisms were plotted without additional filtering in Figure 5. The data from FIP is in binary file format, even though the data from Dynatest, SurPro, and Dipstick are all in ASCII format. The binary file format from FIP is converted to ASCII adding a subroutine to the FAA roughness software, ProFAA, in VB6 for comparison purposes. High speed profilers, FIP and Dynatest profiler, measured full-length 1.85 mile longitudinal pavement surface profiles. Approximately 600 feet test sections from the 1.85 miles were selected and measured by SurPro and Dipstick because of limited operation time at the facility. All the profiles are transformed linearly to set start and end points at same elevations (zero elevation) for comparison purposes. Therefore, the elevation changes in Figure 5 are relative variations compared to the start and end points.

## ANALYSIS

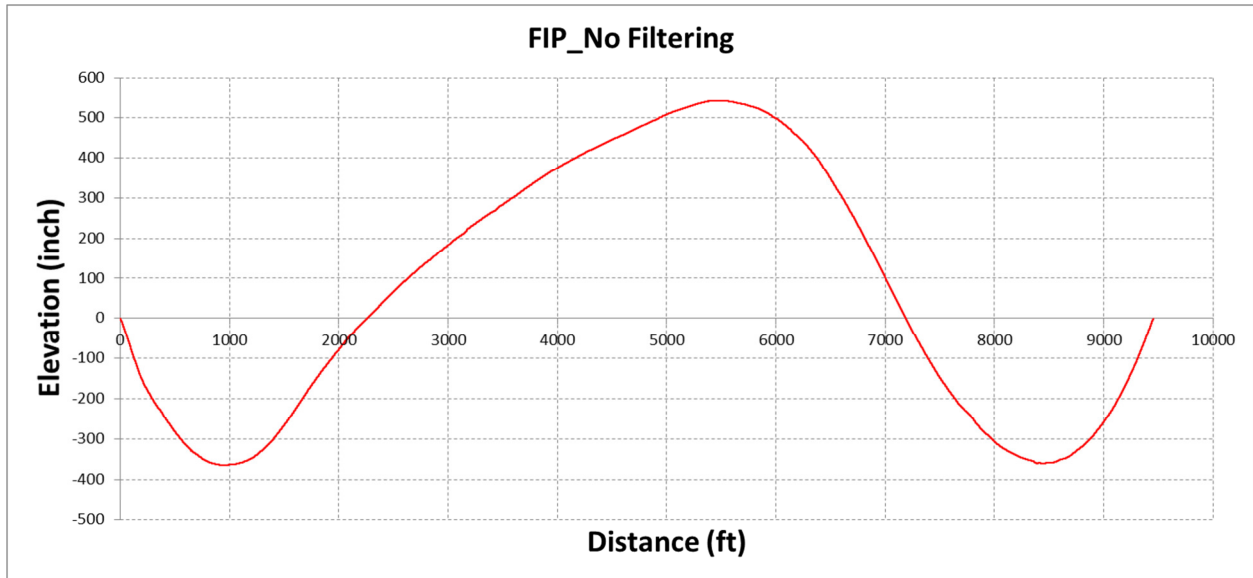
Since the detail information for highway profiler using highpass filtering is not available, the profile data collected from FIP was processed to compare with the Dynatest profiler. For comparisons between the data from FIP and SurPro and Dipstick, the FIP-collected data was reviewed and partial profiles were chosen from the sections corresponding to the locations for SurPro and Dipstick.

### **FAA Inertial Profiler versus Highway Profiler**

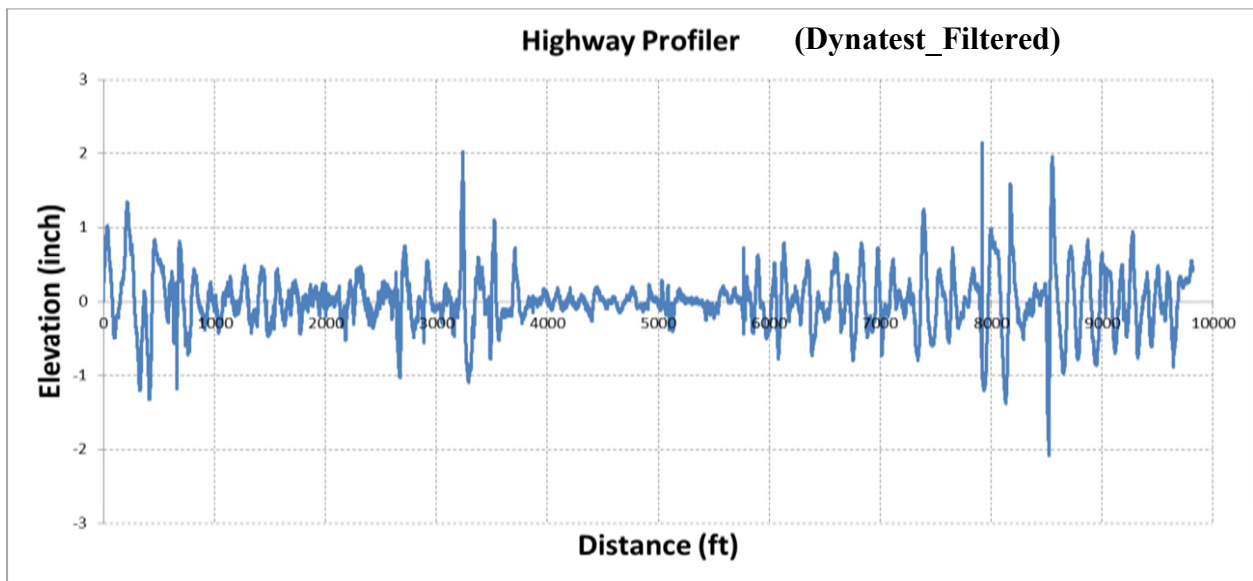
The FAA's AC 150/5380-9 does not recommend using the highpass filter as below [1].

*“...the use of inertial profilers that include highpass filtering is not recommended for measuring profiles which are to be used for computing BBI indexes or simulated airplane accelerations on airport pavements.”*

As described in the AC, BBI and aircraft simulation require longer wavelengths, which are eliminated by highpass filtering. Assuming the collected profiles by Dynatest profiling system go through highpass filter, 300 feet/cy frequency highpass filter with forward only is applied to the FIP collected profiles. The highpass-filtered FIP profiles are shown in Figure 6.



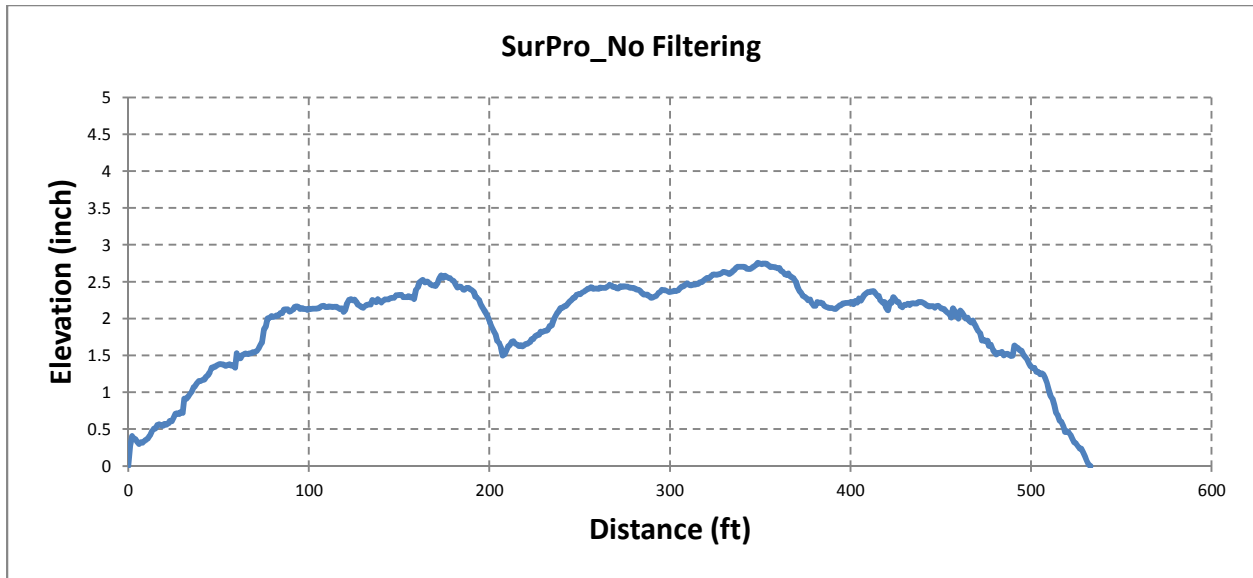
(a)



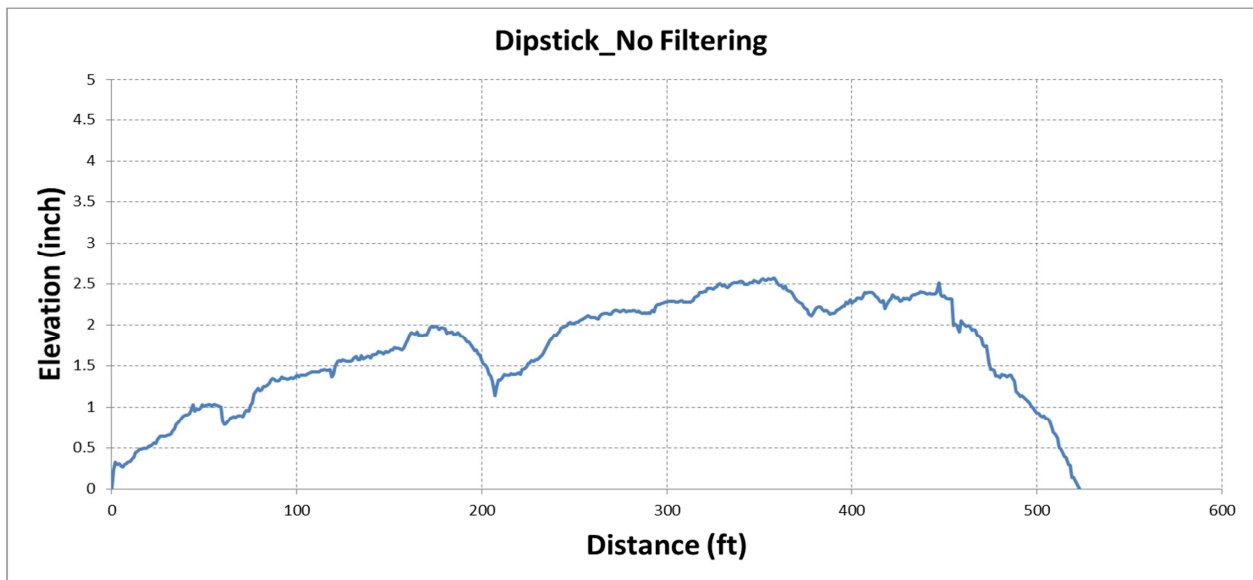
(b)

Figure 5. Collected Longitudinal Profile Data from (a) FIP, (b) Dynatest Profiler, (c) SurPro, and (d) Dipstick.





(c)



(d)

Figure 5 (continued). Collected Longitudinal Profile Data from (a) FIP, (b) Dynatest Profiler, (c) SurPro, and (d) Dipstick.

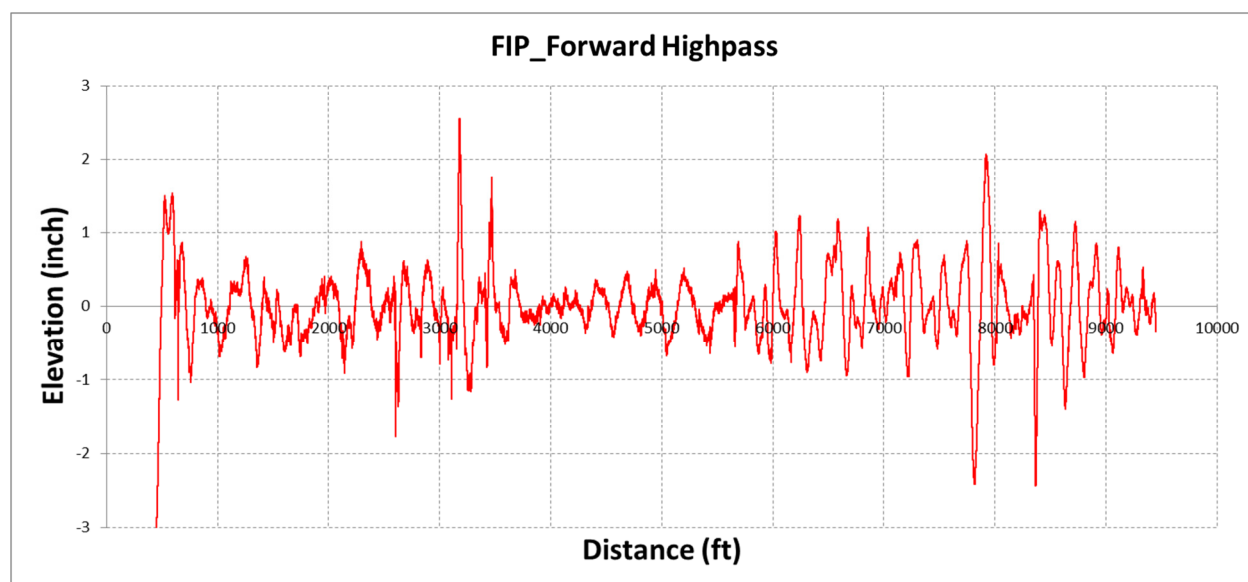
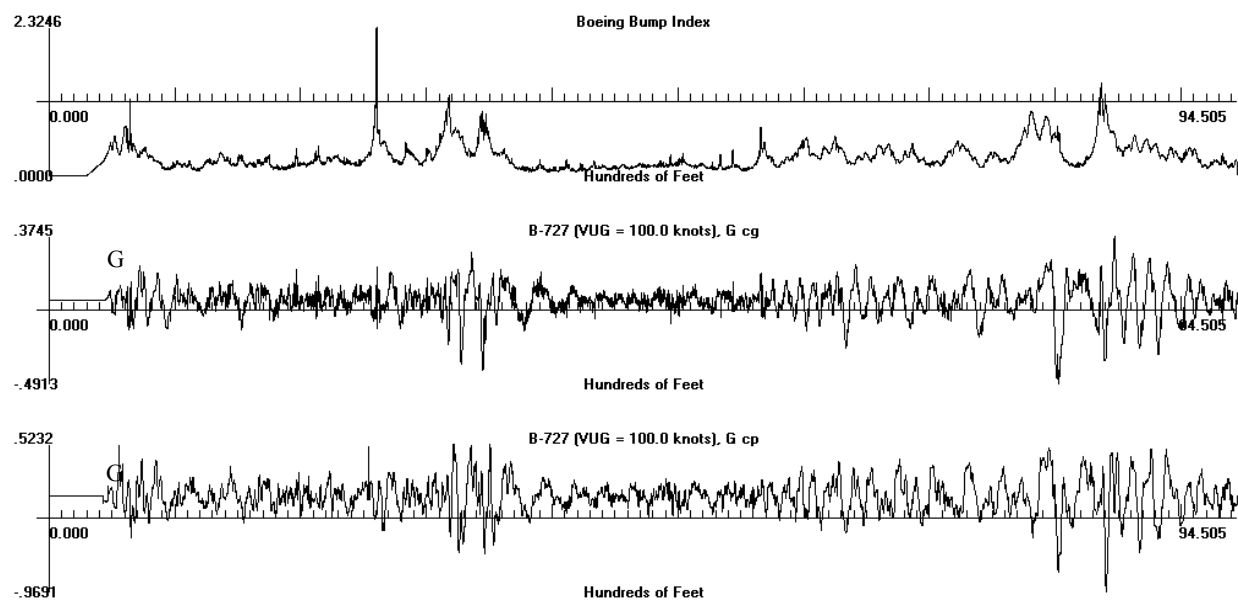
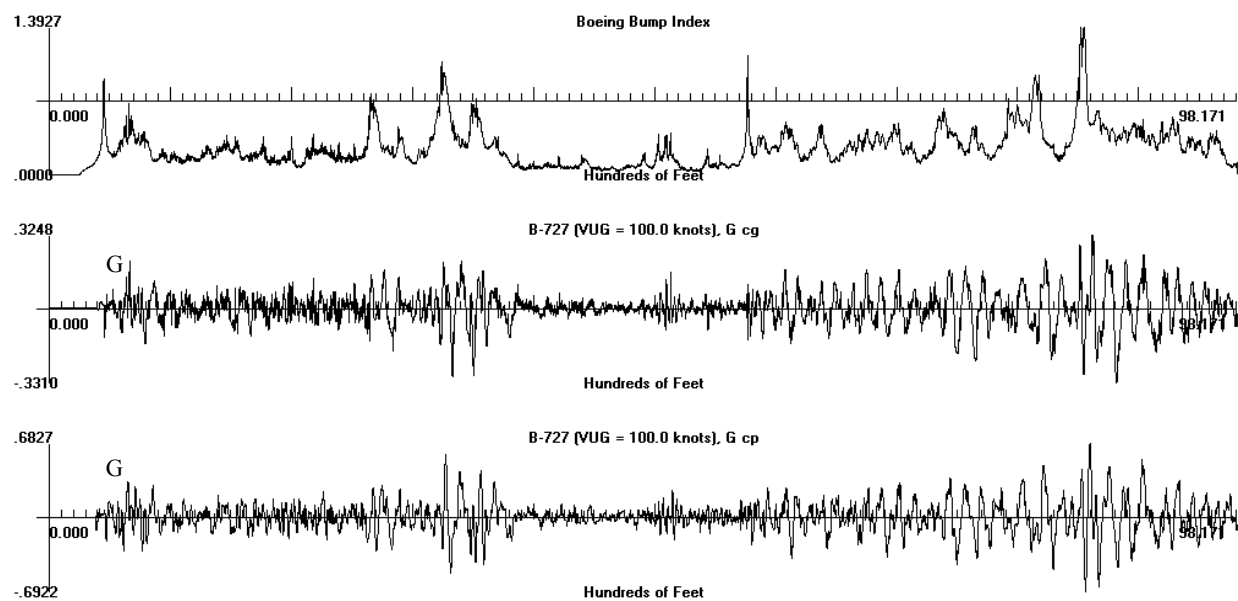


Figure 6. 300 feet/cycle Highpass Filtered FIP Profiles.

Compared to Figure 5 (b), the filtered FIP and highway profiles show strong correlations. Based on the results, the highway profiler adopts forward only 300 feet/cy frequency highpass filter, even though the filtering locations are still not known and whether it is applied at hardware or software after going through all the procedures. The variations of BBI and accelerations at B722 cockpit (Gcp) and center of gravity (Gcg) are simulated at 100 knots aircraft speed on the ground (VUG) and shown in Figure 7 for validating the profile comparisons. Similar BBI values, 0.29 and 0.25, are acquired from FIP and highway profilers, respectively. Similar amplitudes and locations of accelerations are also generated from the two sets of profiles.



(a)

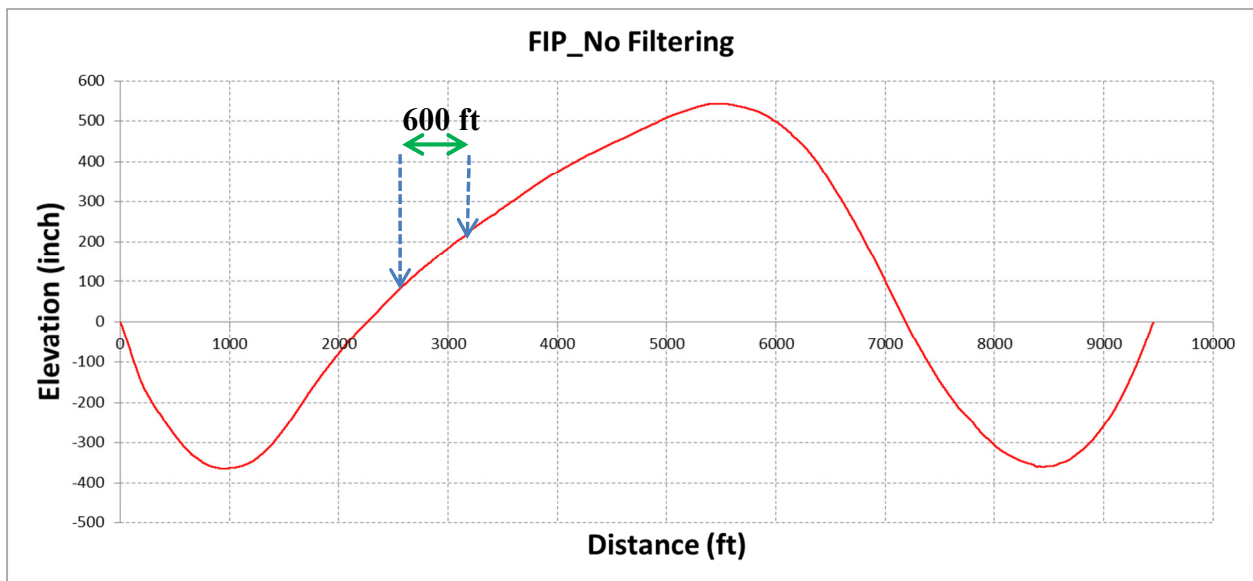


(b)

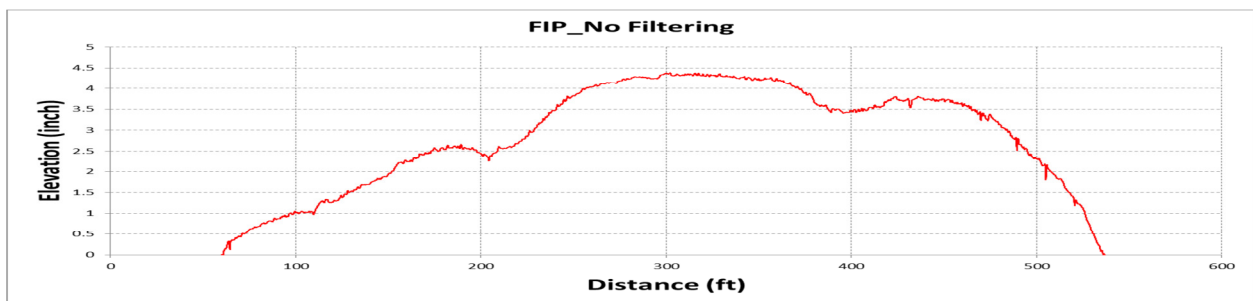
Figure 7. BBI and Accelerations at B727 Center of Gravity and Cockpit (from Top to Bottom) Based on (a) Highpass Filtered FIP Profiles and (b) Highway Profiler Profiles.

### FAA Inertial Profiler versus SurPro and Dipstick

The profile data from FIP is compared to SurPro and Dipstick data. As described earlier, FIP profiles are partially selected to compare with SurPro and Dipstick profiles which are collected for approximately 600 foot test pavement sections. Because of the elevation differences between the start and end points in the FIP's partial profile, linear transform function is used to rotate and make even elevations at start and end points. Figure 8 shows the location and profiles where SurPro and Dipstick profile data were collected in the whole FIP profiles. The FIP section profiles and the SurPro and Dipstick profiles show good correlations corresponding to Figures 8 (b), 5 (c), and 5 (d), respectively. There are some discrepancies in the profile amplitudes for SurPro and Dipstick compared to FIP profiles. They are already identified and discussed by the FAA's previous study on domestic airport runway profiles [4]. It is believed they are created by accelerometer signals as created by any current inertial profiling devices.



(a)



(b)

Figure 8. FIP Profiles from (a) Whole Test Sections and (b) SurPro and Dipstick Test Locations.

### Aircraft Simulations on Single Bump

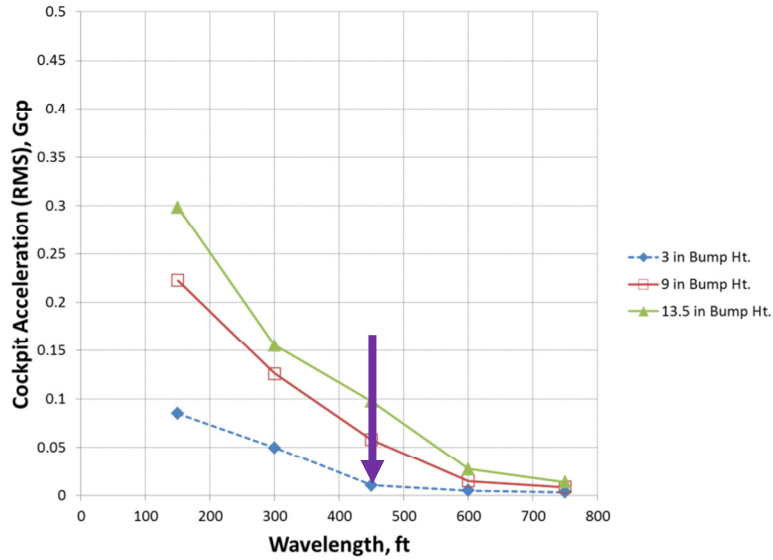
Based on the analysis, the highway profiler uses highpass filtering as presented earlier. Therefore, the needs of 300 feet long and longer wavelengths which is the general cutoff threshold values in highway roughness was confirmed by simulating aircraft responses on artificially constructed half-sine single bumps ranging from 150 to 750 feet with 3, 9, 13.5 inches bump height corresponding longitudinal grades from  $\pm 0.07$  to  $\pm 1.5$  percent following maximum grades for category C & D aircrafts as defined in 150/5300-13A [5]. Table 1 summarizes computed grades for each artificial bump height and widths for the single bumps. A 150 feet width and 3 inches bump height constructing 0.33 percent grade would be more realistic conditions in service airfield pavements.

Table 1. Computed Grades for Each Artificial Bump Height and Width.

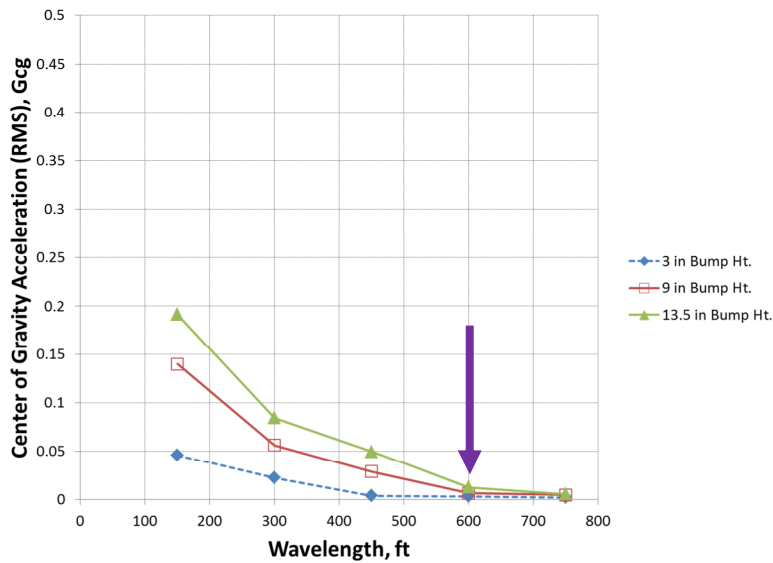
Bump Height, inch	Bump Width, ft				
	150	300	450	600	750
	Grade, %				
3	0.33	0.17	0.11	0.08	0.07
9	1.00	0.50	0.33	0.25	0.20
13.5	1.50	0.75	0.50	0.38	0.30

The single bumps were plotted using the FAA's roughness program ProFAA followed by B727-200 aircraft simulations at accelerations at cockpit (Gcp) and center of gravity (Gcg) with 100 knots simulation speed and 0.025 damping factor. Figure 9 shows computed accelerations at Gcp and Gcg, respectively. As expected, the aircraft simulations show sensitive responses on 300 and longer wavelengths for all the bump heights. Note that, in the figure, the sensitivities of 3 inches bump height decrease significantly after 450 feet wavelengths. The 9 and 13.5 inch bump height lines converges after 600 feet wavelengths. In any case, this analysis confirms that wavelengths equal or longer than 300 feet should be considered for airfield roughness.





(a)



(b)

Figure 9. ProFAA Simulated B727 Computed Accelerations at (a)  $G_{cp}$  and (b)  $G_{cg}$ .

## CONCLUSION

The FAA owned profiling devices including inertial and inclinometer profilers collected pavement surface profiles and compared them. Because the highpass filtering is used in the highway inertial profiler, wavelengths needed for airfield roughness are eliminated. It is suggested to inactivate the highpass filtering procedures removing longer wavelengths for

highway profiler to be used for airfield pavement roughness as described in the AC 150/5380-9 [1].

Arbitrary single bumps with different wavelength and height were created for wavelength sensitivities using aircraft simulation function in ProFAA. The sensitivity analysis presented effective wavelengths required for airport runway pavements for given conditions in terms of accelerations at aircraft cockpit and center of gravity. In any case, this analysis confirms that wavelengths equal or longer than 300 feet should be considered for airfield roughness. The sensitivity analysis would be needed to extend to other aircrafts having different configurations and characteristics.

## **ACKNOWLEDGMENT**

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